CALIFORNIA
ENERGY
COMMISSION

ENERGY INNOVATIONS SMALL GRANT PROGRAM
Strategic Energy Research

Increasing Efficiency of Geothermal Energy Generation with High Resolution Seismic Imaging

FEASIBILITY ANALYSIS

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LEGAL NOTICE

PREFACE

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million of which $2 million/year is allocated to the Energy Innovation Small Grant (EISG) Program for grants. The EISG Program is administered by the San Diego State University Foundation under contract to the California State University, which is under contract to the Commission.

The EISG Program conducts four solicitations a year and awards grants up to $75,000 for promising proof-of-concept energy research.

PIER funding efforts are focused on the following six RD&D program areas:

- Residential and Commercial Building End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research

The EISG Program Administrator is required by contract to generate and deliver to the Commission a Feasibility Analysis Report (FAR) on all completed grant projects. The purpose of the FAR is to provide a concise summary and independent assessment of the grant project using the Stages and Gates methodology in order to provide the Commission and the general public with information that would assist in making follow-on funding decisions (as presented in the Independent Assessment section).

The FAR is organized into the following sections:

- Executive Summary
- Stages and Gates Methodology
- Independent Assessment
- Appendices
    - Appendix A: Final Report (under separate cover)
    - Appendix B: Awardee Rebuttal to Independent Assessment (Awardee option)

For more information on the EISG Program or to download a copy of the FAR, please visit the EISG program page on the Commission's Web site at:
http://www.energy.ca.gov/research/innovations

or contact the EISG Program Administrator at (619) 594-1049 or email eisgp@energy.state.ca.us.

For more information on the overall PIER Program, please visit the Commission's Web site at http://www.energy.ca.gov/research/index.html.

Executive Summary

Introduction

This project targeted an important energy source in California, geothermal energy. The researched seismic imaging technology has the potential to reduce the cost and risk associated with exploration and development of geothermal resources. This technology may lead to increased utilization of California's extensive geothermal resources, which provide an environmentally sound alternative to fossil fuels.

High-resolution reflection seismic imaging has been very successful in oil and gas exploration. It is the number one pre-drilling risk reduction technology and is applied on a routine basis to oil and gas exploration and production projects. Seismic technology has substantially reduced exploration cost, exploration risk, and environmental impacts. Despite its promise, reflection seismic imaging has not been applied extensively or with great success to geothermal exploration.

This project has applied existing, tested, oil and gas exploration algorithms to geothermal field seismic imaging data. The results demonstrated the potential utility of high-resolution reflection seismic imaging applied to geothermal objectives. They represent an improvement over previous research results and demonstrate that application of state-of-the-art seismic imaging technology and methodology may be beneficial in geothermal applications.

Objectives

The goal of this project was to determine the feasibility of applying high-resolution reflection seismic imaging in the geothermal environment to map geothermal reservoir zones. The researcher established the following project objectives:

1. Modify imaging algorithms for application to the seismic imaging data acquired at the Coso geothermal field.
2. Preprocess reflection seismic data acquired at the Coso geothermal field.
3. Generate a high-resolution wave equation migrated image of the Coso geothermal field.
4. Determine the validity and accuracy of seismic imaging by comparison to drilling data, other geological/geophysical information, and prior processing results.

Outcomes

1. The researcher made minor modifications to the algorithms to read and to fully utilize the Coso geothermal field seismic imaging data.
2. The researcher implemented a near-surface velocity model using first-arrivals from the seismic data and turning ray tomography inversion. This implementation removed near-surface distortions.
3. The researchers generated high-resolution wave equation migrated images of the Coso geothermal field using each of the following methods: a) 3DGeo's ComAz wave-equation migration algorithm, b) prestack time migration, c) post stack time migration, and d) prestack Kirchhoff depth migration.
4. The researcher compared the images to prior existing images, published geological and geophysical information, and analyses. The project compared the velocity models to results previously obtained by other workers. The project validated the new high-resolution images against the known geology.

Conclusions

1. This project has taken the first step in validating the application of 3DGeo's proprietary seismic imaging technology to a California geothermal data set.
2. Geothermal areas generally produce challenging seismic data that push the limits of processing and imaging technology. This project has demonstrated the challenges can be overcome through the proper application of state-of-the-art seismic imaging technology.
3. Active source reflection seismology appears to offer benefits to geothermal exploration and development. High quality seismic data processing is important to obtain accurate and usable imaging results. The quality processing is not limited to the high-end imaging algorithms such as Kirchhoff migration, but also is valuable in the preprocessing applied to data. Statics and prestack noise attenuation appear to be important to obtain a good imaging result.
4. The images generated in this project appear to support the proposed methodology for processing geothermal field seismic data. The major goal of this study was to demonstrate that seismic imaging of structures could be obtained in heterogeneous geothermal environments. Therefore, the researcher assessed the success of the experiment by reference to the seismic imaging results themselves and the fact that knowledgeable geophysicists could identify known geologic structure from the images. While interpreting the images remains an art, there does appear to be more details in the new images that have a positive correlation to the known geology.

Benefits to California

Because this technology can lower the cost of finding and producing geothermal energy the electric ratepayer will receive economic and environmental benefits. The California Legislature recently passed SB1078 that mandates utilities to provide 20% of their electricity from renewable resources by 2017. Technologies such as the one demonstrated in this grant will both lower the cost of developing the required resources, and also may lead to discovery of more geothermal resources within the State. The increased utilization of California's renewable geothermal resources will benefit the State as a whole by reducing the need to import and consume increasingly costly conventional fuels. Reduced consumption of fossil fuel will also improve California’s air quality.

Recommendations

The PA recommends further processing of the remaining Coso data. Researchers should acquire another 2-D or preferably 3-D survey in Coso or elsewhere for further imaging and demonstration of the technology in a larger more in-depth effort. Further development of this technology through a large-scale demonstration will clarify its capability by giving an example of its full potential.

Stages and Gates Methodology

The California Energy Commission utilizes a stages and gates methodology for assessing a project's level of development and for making project management decisions. For research and development projects to be successful they need to address several key activities in a coordinated fashion as they progress through the various stages of development. The activities of the stages and gates process are typically tailored to fit a specific industry and in the case of PIER the activities were tailored to be appropriate for a publicly funded energy research and development program. In total there are seven types of activities that are tracked across eight stages of development as represented in the matrix below.

Development Stage/Activity Matrix

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
Activity 1								
Activity 2								
Activity 3								
Activity 4								
Activity 5								
Activity 6								
Activity 7								

A description the PIER Stages and Gates approach may be found under "Active Award Document Resources" at: http://www.energy.ca.gov/research/innovations and are summarized here.

As the matrix implies, as a project progresses through the stages of development, the work activities associated with each stage needs to be advanced in a coordinated fashion. The EISG program primarily targets projects that seek to complete Stage 3 activities with the highest priority given to establishing technical feasibility. Shaded cells in the matrix above require no activity, assuming prior stage activity has been completed. The development stages and development activities are identified below.

Development Stages:		Development Activities:	
Stage 1:	Idea Generation & Work Statement Development	Activity 1:	Marketing / Connection to Market
Stage 2:	Technical and Market Analysis	Activity 2:	Engineering / Technical
Stage 3:	Research & Bench Scale Testing	Activity 3:	Legal / Contractual
Stage 4:	Technology Development and Field Experiments	Activity 4:	Environmental, Safety, and Other Risk Assessments / Quality Plans
Stage 5:	Product Development and Field Testing	Activity 5:	Strategic Planning / PIER Fit - Critical Path Analysis
Stage 6:	Demonstration and Full-Scale Testing	Activity 6:	Production Readiness / Commercialization
Stage 7:	Market Transformation	Activity 7:	Public Benefits / Cost
Stage 8:	Commercialization		

Independent Assessment

For the research under evaluation, the Program Administrator assessed the level of development for each activity tracked by the Stages and Gates methodology. This assessment is summarized in the Development Assessment Matrix below. Shaded bars are used to represent the assessed level of development for each activity as related to the development stages. Our assessment is based entirely on the information provided in the course of this project, and the final report. Hence it is only accurate to the extent that all current and past work related to the development activities are reported.

Development Assessment Matrix

Stages / Activity	1 Idea Generation	2 Technical & Market Analysis	3 Research	4 Technology Develop-ment	5 Product Develop-ment	6 Demon-stration	7 Market Transfor-mation	8 Commer-cialization
Marketing								
Engineering / Technical								
Legal/ Contractual								
Risk Assess/ Quality Plans								
Strategic								
Production. Readiness/								
Public Benefits/ Cost								

The Program Administrator's assessment was based on the following supporting details:

Marketing/Connection to the Market

The market for seismic imaging technology is energy companies involved in development of geothermal resources in California and worldwide. Preliminary research assessed the potential market size and identified target customers. However, the greatest benefit of this technology will accrue to the State and to ratepayers in the form of increased geothermal development and reduced costs. A product is ready for market (Stage 4) and the technology has outperformed the competition (Stage 5).

Engineering/Technical

A test plan is outlined in the Recommendations section of Appendix A. Parts of Stage 4 (candidate site), Stage 5 (field test at Coso), and 6 (initial 2-D demonstration) were accomplished as part of this EISG project.

Legal/Contractual

U.S. Patents have been issued, and several are pending on certain key 3DGeo technologies that have been applied in this EISG project. Patents applications are based on work accomplished prior to this grant.

Environmental, Safety, Risk Assessments/ Quality Plans

Application of this technology to geothermal exploration and exploitation reduces environmental risk through reduction in drilling errors, and reduction of cross-contamination of aquifers and reservoirs. This project has laid the groundwork for developing a Quality Plan to assess the reliability and applicability of the technology in applications to different geothermal areas.

Quality Plans include Reliability Analysis, Failure Mode Analysis, Manufacturability, Cost and Maintainability Analyses, Hazard Analysis, Coordinated Test Plan, and Product Safety and Environmental.

Strategic

This product has no known critical dependencies on other projects under development by PIER or elsewhere. It offers a technology to exploit and expand the scope of geothermal development in California. This project extends the scope of, and is complimentary to, known Federal R&D programs.

Production Readiness/Commercialization

The seismic imaging technology demonstrated in this EISG project is nearly production ready. Further field demonstration of the technology, as outlined in the recommendations for further work (See Appendix A), would validate the production readiness. The researcher's company, 3Dgeo Development Inc., could take this technology directly to market.

Public Benefits

Public benefits derived from PIER research and development are assessed within the following context:

- Reduced environmental impacts of the California electricity supply or transmission or distribution system.
- Increased public safety of the California electricity system
- Increased reliability of the California electricity system
- Increased affordability of electricity in California

The primary benefit to the ratepayer from this research is increased affordability of electricity in California because this technology can lower the cost of finding and producing geothermal energy. Benefits of this technology to geothermal energy generation development in California are reductions in cost of development step-out production wells and injection wells, potentially saving 3 to 5 wells per 100 MW developed in a large new field and 2 to 3 wells in a small 35 MW field for which drilling risk per MW is typically higher. These wells can cost $1.5 to $4 million each including access costs. This cost comes at an estimated investment of $1 million in seismic to save up to $20 million in drilling cost. That is a return on investment (ROI) of 20 for a 100 MW field. These costs are likely to go down as further experience is gained and as more reflection seismic data is collected in geothermal fields.

There is commercial interest in demonstration testing, as exemplified by the donation of the seismic data to this project by the Coso operators.

Appendix A: Final Report (under separate cover)

Appendix B: Awardee Rebuttal to Independent Assessment (none submitted)